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Multi-Objective Optimization Technique for Power System Hybridization

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Abstract—*In recent years, rise in the cost of energy derived from fossil fuels and enhanced public awareness of the potential impact on the environment of conventional energy systems has created an increased interest in the development and utilization of alternate sources, such as wind and solar energy. The application of these nonconventional energy sources appear to be most cost effective when providing basic energy needs to small communities located in remote isolated areas. Wind energy and PV systems require no fuel and can therefore be included in hybrid power system to compensate costly diesel fuel. The associated maintenance cost is also relatively high and is a factor of operating time. The cost of transporting fuel to remote locations and providing storage is quite significant in many cases. New policies formulated to reduce global warming have associated penalties with the use of fuels that emit greenhouse gases.*

Keywords:—*Wind energy, solar energy, PV system.*

1. INTRODUCTION

In recent year hybrid energy systems are using to generate electricity on large scale. Rapid depletion of fossil fuel resources, rising concern over air pollution and global warming have stimulated interest in reducing greenhouse gas (GHG) emissions, including those emitted during electricity generation from conventional sources like coal, oil, and natural gas. Therefore in view of above problems researchers have now focused on development of technology i.e. Renewable Energy Sources (RES) based power generation. World is moving slowly but steadily towards renewable energy because these are inexhaustible, pollution free and available abundantly.RES are expected to play a significant role in order to fulfil future demand [1,2]. The scope of Conventional energy sources are limited so renewable energy sources such as wind, solar etc. are exist in those areas. Renewable energy sources can enhance diversity in energy supply market and reduce local and global emission. This paper describes hybridization of solar and wind power. World primary energy consumption is expected to grow by 1.6% per annum from 2011-2030 adding 36% to the total form 2011. By 2011 the bulk share of energy was provided by coal(41%), then gas(22%), oil(4%) all total contribution of fossil fuel was 67%, nuclear 13%, renewable energy 20%. Between 2011-2030 growth of renewable is expected to be 7.6% per annum, which is highest compared to other sources of energy[3]. The advantages can be maximized only when optimal planning of hybrid systems with respect to size and location has been carried out. A comprehensive evaluation of reliability and cost is required to analyze the actual bench of utilizing these energy sources. The reliability aspects of utilizing renewable energy sources have largely been ignored in past due to relatively insignificant contribution of these sources in power systems. However reliability aspect cannot be ignored due to increasing penetration. In this study emphasize over two objects system cost and reliability in term of optimization of sizing of RES based hybrid system using particle swarm optimization. Solar and wind energy characteristics attracted the energy sector to use renewable energy sources on a large scale.

2. LITERATURE REVIEW

Panwar et al reviewed the renewable energy sources to define role of renewable energy sources (RES) for environmental protection. In their study, it is emphasized that renewable technologies are clean energy sources and optimal use of these resources minimize negative environmental impacts, produce minimum secondary wastes and provide a sustainable world.

Morgan et al. incorporated battery units in a standalone hybrid energy system at various temperatures by taking into account the state of voltage (SOV) instead of the state of charge (SOC). The algorithm is able to predict the performance of a hybrid energy system at various battery temperatures. This study is important for efficiency of a hybrid energy system because temperature affects the performance of a PV array and battery unit.

Madhav Singh Thakur et al reviewed about hybrid system for sustainable and economic power supply. For this purpose they used LINDO and HOMER software to optimization of hybrid system for solar and wind.

Deepak Kumar Lal et al : Their work was proposed on a hybrid power generation system suitable for remote application area. This concept shows that the hybridization of renewable energy sources is that the base load is to covered by largest and firmly available renewable energy sources and other intermittent sources.

Borowy et al. developed an algorithm to optimize a photovoltaic-array with battery bank for a standalone solar-wind hybrid energy system. The model is based on a long-term hourly solar radiation and peak load demand data from the site. In this study, direct cost of the solar-wind hybrid energy system is considered.

Angelis-Dimakis et al. have evaluated the availability of renewable energy sources such as solar, wind wave, biomass and geothermal energy. In their research, a detailed survey including existing methods and tools to determine the potential energy in renewable resources is presented. Also, tendency of using the renewable energy by the most developed countries in order to reduce the concentration of carbon dioxide in the atmosphere is emphasized. The study also mentions the usability of hybrid energy system by mixing different renewable sources.

3. PROBLEM FORMULATION

The basic function of an electric power system is to satisfy the system load demand and requirements of power as economically as possible and with a reasonable assurance of continuity and quality. The two aspects of relatively low cost of electrical energy at a high level of reliability are often in direct conflict and present an important problem in determining an appropriate generating reserve capacity margin. Numerous hybrid systems have been installed across the world, and expanding renewable energy industry has now developed reliable and cost competitive systems using a variety of technologies.

Power system reliability evaluation is one of the most important process in the system planning and designing in order to ensure healthy system operation in the future.

In this work Loss of Power Supply Probability (LPSP) criteria are used for reliability evaluation. LPSP defines the probability that a system demand will exceed the generating capacity during a given period. Reliability of the system has been expressed in terms of LPSP. LPSP can be calculated in term of expected energy not served (EENS) as follows:

$$LPSP = \frac{EENS}{E}$$

The EENS (kWh/year) for the duration under consideration T (8760 h) can be calculated as follows

$$EENS = \sum_{t=1}^{T} \left(P_{b_{\min}} - P_{b_{soc}}(t) - P_{\sup}(t)\right) \times U(t)$$

where

EENS	Expected energy not served in KWh/year
E	Yearly energy demand in KW
P_{bmin}	Minimum storage capacity of the batteries
U(t)	Unit step function

U (t) is a step function that value is zero when the supply exceeds or equals to the demand and equals to one if there is insufficient power in period t.

Economic Evaluation

Current power crises throughout the world have led to an extensive research and development of new technologies for generation of power to meet present energy demand. New sources of energy are continuously being explored and extensive research is being carried out to reduce cost of generation of power. Cost estimation has been incorporated into the hybrid generation system design. The total cost ($/year) includes initial cost, operational and maintenance (OM) cost for each type of power source, and the salvage value of each equipment which should be deducted.

$$COST = \frac{\sum_{i=w,s,b} (I_i - S_{P_i} + OM_{P_i})}{N_P}$$

Where w, s, b indicate the wind power, solar power, and battery storage, respectively; I_i, S_{pi}, OM_{pi} are the initial cost, present worth of salvage value, and present worth of operation and maintenance cost (OM) for equipment *i*, respectively; *Np* (year) is the lifespan of the project. Here, we assume that the lifetime of the project does not exceed those of both WTGs and PV arrays.

Cost for Wind Turbine Generator

Initial cost of the WTGs is

$$I_w = \alpha_w \times A_w$$

Present worth of the total salvage value is

$$S_{P_w} = S_w \times A_w \times \left(\frac{1+\beta}{1+\gamma}\right)^{N_P}$$

Present worth of the total OM in the project lifetime is

$$OM_{P_w} = \alpha_{OM_w} \times A_w \times \sum_{i=1}^{N_P} \left(\frac{1+\nu}{1+\gamma}\right)^i$$

where

α_w	Initial cost of WTGs in $/m^2
S_w	Salvage value of WTGs in $/m^2
β	Inflation rate
γ	Interest rate
α_{OMw}	Yearly O&M cost of WTGs in $/m^2/year
ν	Escalation rate
N_p	Life span of the project in year

Cost for Photovoltaic Panels

The initial cost is

$$I_s = \alpha_s \times A_s$$

Present worth of the total salvage value is

$$S_{P_s} = S_s \times A_s \times \left(\frac{1+\beta}{1+\gamma}\right)^{N_P}$$

Present worth of the total OM in the project life time is

$$OM_{P_s} = \alpha_{OM_s} \times A_s \times \sum_{i=1}^{N_P} \left(\frac{1+\nu}{1+\gamma}\right)^i$$

where

α_s	Initial cost of PV panel in $/m^2
S_s	Salvage value of PVs in $/m^2
β	Inflation rate
γ	Interest rate
α_{OMw}	Yearly O&M cost of PVs in $/m^2/year
ν	Escalation rate
N_p	Life span of the project in year

Cost of Storage Batteries

Since their lifespan is usually shorter than that of the project, the total present worth of capital investments can be calculated as:

$$I_b = \alpha_b \times P_{b_{cap}} \times \sum_{i=1}^{X_b} \left(\frac{1+\nu}{1+\beta}\right)^{(i-1)N_b}$$

Salvage value of SBs is ignored in this study and present worth of the total O&M cost in the project lifetime is calculated as follows:

$$OM_{P_b} = \alpha_{OM_b} \times P_{b_{cap}} \times \sum_{i=1}^{N_P} \left(\frac{1+\nu}{1+\gamma}\right)$$

where

α_s	Initial cost of SBs in $/m^2
N_b	Lifespan of SBs in year
X_b	Number of times to purchase batteries
N_p	Life span of project in year
β	Inflation rate
ν	Escalation rate
γ	Interest rate
α_{OMb}	Yearly O&M cost of SBs in $/KW/m^2

4. OPTIMIZATION METHODOLOGY

Various optimization methods are classified based on type of the search space and objective function. The various optimization techniques are analytic technique, particle swarm optimization, genetic algorithm, tabu search and ant colony optimization.

The hybrid system optimization problem can be treated as a multi-objective design. The considered objectives are defined as:

Objective 1: Minimizing the system life cycle cost.

Objective 2: Maximizing the system reliability.

In multi-objective optimization both the objectives that is cost and reliability are optimized by applying a Particle swarm optimization (weighted sum method). Both the objective function should be linear.

$$Function = W_1 \times COST + W_2 \times LPSP$$

Sum of both the weight factor is always one.

$$W_1 + W_2 = 1$$

Where

W_1	Weight factor for cost
W_2	Weight factor for LPSP

Constraints

The swept area of WTGs should be within a certain range

$$A_{w_{min}} \le A_w \le A_{w_{max}}$$

The area of PV arrays should also be within a certain range

$$A_{s_{min}} \le A_s \le A_{s_{max}}$$

where

A_{wmin}	Minimum wind swept area in m^2
A_{wmax}	Maximum wind swept area in m^2
A_{smin}	Minimum PV panel area in m^2
A_{smax}	Maximum PV panel area in m^2

5. RESULT AND CONCLUSIONS

The determination of optimal sizing based on developed formulation has been carried out for an HPS located in Bhopal, Madhya Pradesh, India. The peak load of HPS considered in this study has been assumed as 75KW. The load is assumed to be constant for a particular time segment. Each time segment is assumed to be of 1 hour. Thus, study period of one year comprises of 8760 segments. Life span of project has been considered 20 year and life span of PV panel is equal to life span of project. Life span of storage battery has been considered 10 year. Hence storage battery is replaced one time during projected life span.

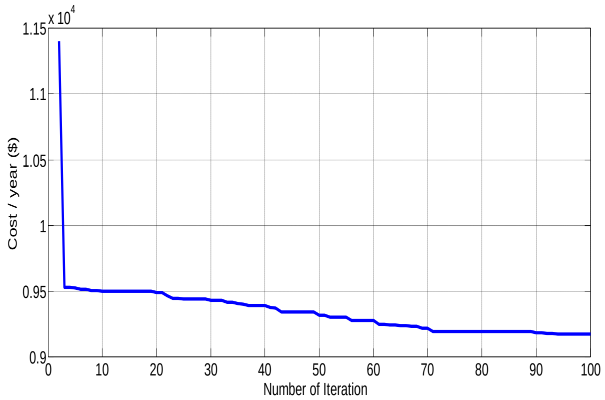

Figure 1. Convergence Characteristic of Cost/year with Constant Inertia Weight Factor

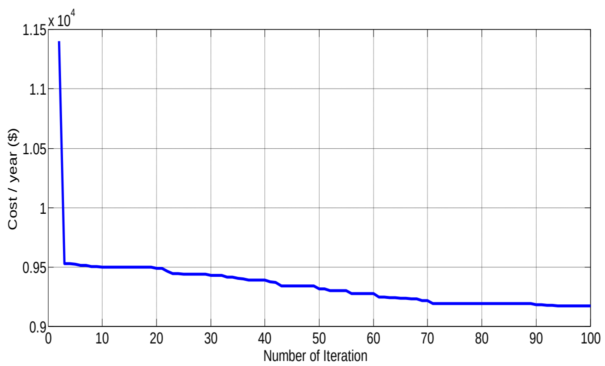

Figure 2. Convergence Characteristic of Cost/year with Linear Decreasing Inertia Weight (LDIW) Factor

It is observed from figure that cost per year of the HPS are converge with inertia weight factor is considered unity and figure 2 shows an cost per year of the HPS are converge by considering linear decresing inertia weight factor. Equation 5.3 calclate the value of linear inertia weight factor. In which considered the value of W_{min} is 0.4 and W_{max} is 0.9 to get better convergence as compared to the figure 1. It is shown by comparing both the figure.

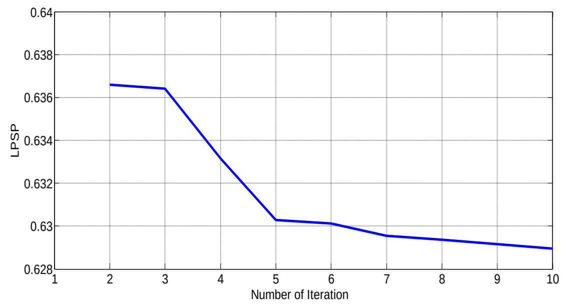

Figure 3: Convergence Characteristic of LPSP with Constant Inertia Weight Factor

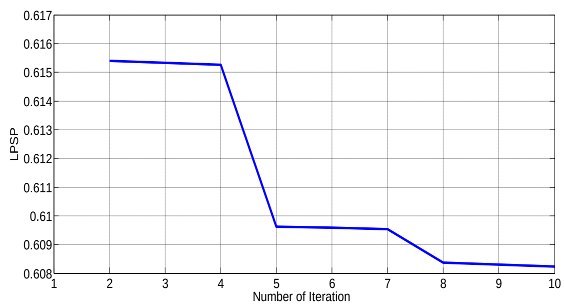

Figure 4 : Convergence Characteristic of LPSP with Linear Decreasing Inertia Weight (LDIW) Factor

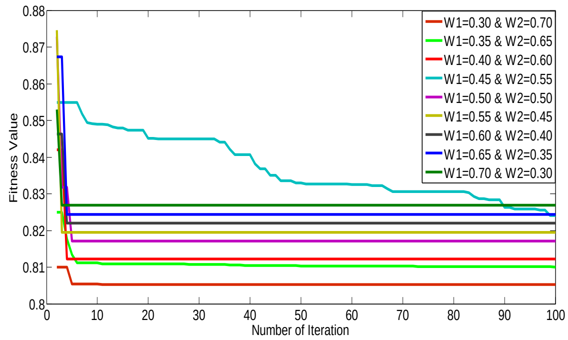

Figure 5: Convergence Characteristics of Fitness Value

6. FUTURE SCOPE

The Future Scope of this paper to determination optimal sizing based on developed formulation has been carried out for any location and any KW. The load is constant for a particular time segment.

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